Photonuclear Physics Options in the MCNP6 Transport Code

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Physics Options in MCNP6

Using Tabulated Data Libraries

- Interaction probabilities and secondary particle distributions (i.e. multiplicity, angle, energy) are evaluated, processed and provided in data tables
- Typical for neutrons, photons, and electrons in the “low-energy” range
- Also limited availability of proton, deuteron, triton, ^{3}He and ^{4}He particles incident on certain targets

Using Physics Models

- For other particle types (pions, kaons, heavy ions, etc.), and particles with high energies above the table ranges, inline physics models are used for on-the-fly computation of interaction probabilities, secondary particle production, etc.
- Many models are Monte Carlo in nature and have defined particle types and energy ranges where most applicable

Photonuclear Physics Libraries

- Typical upper energy limit of ~150 MeV
- A photonuclear interaction begins with a photon absorption by a nucleus through the giant dipole resonance or quasi-deuteron absorption
- To be used by MCNP6, libraries are processed into ACE format
- Two libraries have been released with previous versions of the MCNP code

LA150U, 13 isotopes, released ~2000

^{2}H, ^{12}C, ^{16}O, ^{27}Al, ^{28}Si, ^{40}Ca, ^{56}Fe, ^{63}Cu, ^{181}Ta, ^{184}W, ^{206}Pb, ^{207}Pb, ^{208}Pb

ENDF7U, 157 isotopes, released ~2006

- A superset of LA150U, including all 13 isotopes and 144 additional isotopes
- Based on IAEA CRP efforts and ENDF/B-VII.0

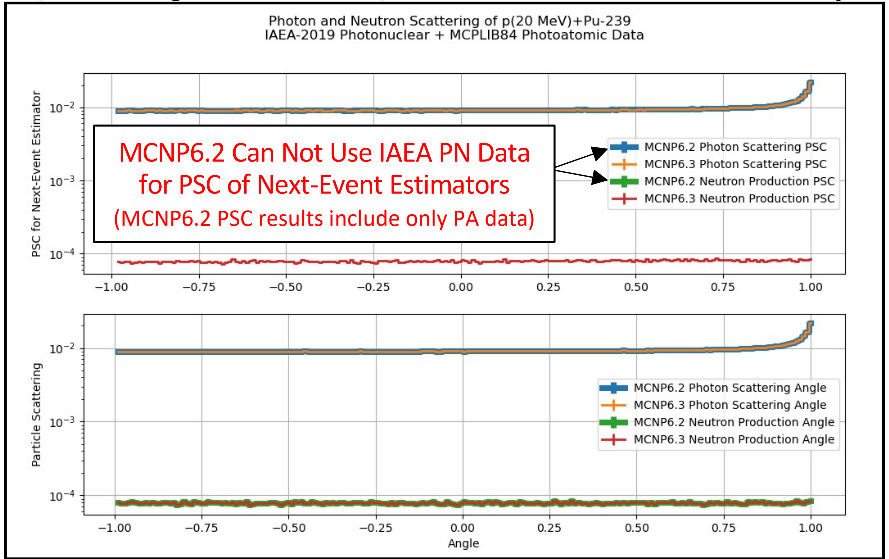
See Refs. [1-4]

Recent Photonuclear Library Improvements in MCNP6.3

- Traditional photonuclear data relied on limited scattering law formats (i.e. single Legendre coefficient giving isotropic distributions)

- The more recent IAEA CRP on photonuclear cross sections leading to the IAEA-2019 library [5] included anisotropic Legendre expansions of secondary particle distributions

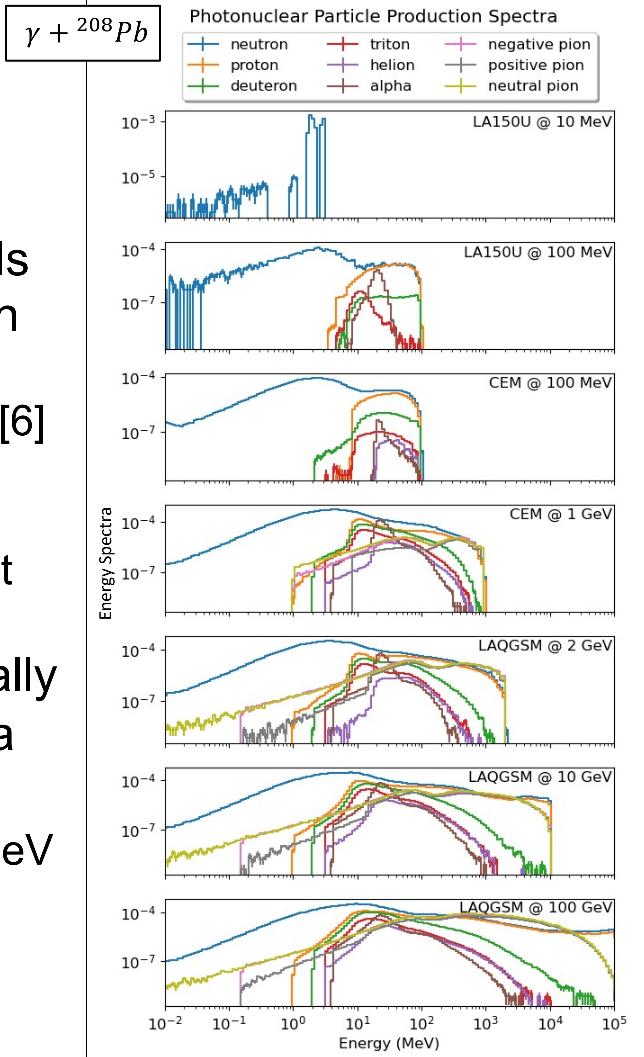
- In the upcoming release of MCNP6 these new scattering laws are handled properly, which required changes to both the MCNP code and the NJOY processing code



Photonuclear Physics Models

- Above the ~150 MeV energy threshold physics models can be used directly inline within the MCNP simulation
  - For incident photon energies above the maximum table energy and <1.2 GeV, the cascade-exciton model (CEM) [6] is used by default
  - For incident photon energies >1.2 GeV, the Los Alamos quark-gluon string model (LAQGSM) [7] is used by default

- This kind of inline event generator approach is generally needed in these energy regimes where tabulated data may be difficult to evaluate and validate
  - For photonuclear physics, pion production occurs ~150 MeV where more complex nuclear modeling is needed



Other Photonuclear Data and Model Considerations

- In the MCNP code, photonuclear physics is off by default – users must opt-in to make use of this physics

- There is quite a bit of flexibility through a mix-and-match approach within MCNP6 to handle are sorts of physics, including photonuclear interactions
  - Mixed use of model and data above and below an energy threshold
  - Selective use of data and model for any nuclide

- The LLNL Fission Library [8], included in all versions of MCNP6 and in later versions of MCNPX, can be used to simulate photofission reactions for a variety of actinides
  - This library does not use the ACE-based data, but is not quite a physics model event generator like CEM, LAQGSM, etc.

Application Uses and Needs

Uses

- Accelerator neutron source studies – photoneutron production
- Accelerator radiation protection
- Special nuclear materials (SNM) detection and active interrogation concepts
- Medical applications, e.g. therapy

Needs

- More complete library (LA150 contains 13 nuclides, 1999 IAEA CRP contains 164 nuclides, and 2019 IAEA CRP contains 219 nuclides)
  - Compare to 550+ neutron reaction sub-library evaluations in ENDF/B-VIII.0
- Experiment data for photofission evaluation and validation of photonuclear data

Conclusions

- Both photonuclear data tables and physics model event generator capabilities exist within the MCNP6 code

- Improvements to MCNP6.3 and NJOY have been made to enable the processing and use of more modern photonuclear data tables

- Many application areas, from accelerators to SNM detection/interrogation

- Validation of photonuclear data and model physics use in transport may be lacking and should be investigated

Questions?

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